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DISTRIBUTION OF MODERATED AND UNMODERATED 14-Mev NEUTRONS IN A SEMI-INFINITE SAMPLE ALONG AN AIR-GROUND INTERFACE

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GSFC — GODDARD SPACE FLIGHT CENTER
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ABSTRACT

A moderated and an unmoderated source of 14-Mev neutrons were used to irradiate a semi-infinite sample of ground. The neutron number and energy distribution were measured with ten BF_3 neutron counters at various distances up to 150 feet. Distribution curves are shown for both thermal and fast components. A peak was observed in the fast component curve, which is explained as an effect of spectrum softening with distance from the source.

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INTRODUCTION

The development of in situ neutron-gamma activation methods for performing rapid qualitative and semiquantitative analyses on semi-infinite geological samples is currently being studied (refs. 1-8). The chemical composition of these samples is inferred by the radioisotopes produced by the neutron flux, and detection is made by gamma-ray spectroscopy. The gamma rays are produced by neutron elastic and inelastic scattering, capture, and activation reactions. The dominant reactions in a given location in the semi-infinite sample depend on the flux and neutron energy distribution. Flux and energy calculations by Monte Carlo methods and also experimental determinations have been made for various homogeneous materials to determine the neutron energy distribution. The calculations (ref. 9) and experiments are generally concerned with a single phase and for distances of a few feet, or at very large distances (refs. 10 and 11). Fundamental to carrying out the measurements and obtaining unique interpretations from the gamma ray pulse height spectra is a knowledge of the flux and energy distribution of neutrons in the intermediate distances in the irradiated media. In order to complete the mapping of this distribution pattern at intermediate distances that is needed to adequately interpret the results, experimental measurements were made of the neutron energy and flux distribution from the neutron source to distances up to 150 feet along an air-ground interface.

EXPERIMENTAL

Procedure

The neutron flux distribution along an air-ground interface in an area of 150-feet radius was measured at a number of locations using paraffin-cadmium-clad, paraffin-clad, and bare neutron BF_3 detectors. A positive ion accelerator-type neutron source was used to produce moderated and unmoderated 14-Mev neutrons. Simultaneous measurements using up to ten detectors were carried out under a variety of weather conditions in the field. To reduce statistical errors, at least three irradiations were made at each location. Each detector was calibrated with a National Bureau of Standards Am-Be neutron source. Normalized flux-distance curves were obtained for unmoderated and moderated 14-Mev neutrons.

Apparatus and Technique

The neutron source was a 200-kv Cockroft-Walton-type accelerator using an $H^3(d,n)He^4$ reaction to produce about 10^8— 10^9 neutrons cm^{-2} sec^{-1} of monoenergetic neutrons. Provision was made to insert approximately six inches of paraffin between the ground and the accelerator target to moderate the neutron flux. In addition, a large 60-gallon annular-shaped vessel was placed around and just above the target. To scatter the neutrons emitted in an upward direction and those reflected from the ground, this vessel was filled with paraffin oil. The accelerator and moderator are mounted on the lift-gate of a heavy-duty vehicle and can be adjusted to any height above the ground up to approximately 40 inches.

The amplifiers, scaling circuits, and power supplies were mounted in a second vehicle and stationed about 500 feet from the accelerator, for the safety of personnel. The BF_3 detectors and preamplifiers situated at the fixed locations from the accelerator were cable-connected to the electronic counting systems. At each counting location, a shallow hole 8 inches in diameter and about 15 inches deep was made in the soil. BF_3 detectors were placed in hole, each alternatively with and without a 1.5-inch paraffin sheath and a cadmium cover. In addition, each hole was provided with a cadmium and 4-inch paraffin cover. The ten holes were located at fixed distances from the neutron source as shown in Table 1. A ZnS-plastic scintillator neutron detector was used to monitor the neutron flux from the source; it was placed in a fixed position close to the accelerator.

Before flux measurements were made, the plateau and relative efficiencies were determined for each counter. With each detector in position, the accelerator was turned on for a preset two-minute period; a simultaneous count was made of each location. The counts and each repeated set of data were normalized to each other. The mean of all data was taken as the final result.

Table 1

Detector Positions at Distances Measured from the Source

Hole Number	Distance from Source (ft)
1	2.3
2	4.0
3	6.5
4	12.1
5	18.0
6	41.0
7	60.0
8	80.0
9	124.0
10	150.0

RESULTS AND DISCUSSION

Moderated Neutrons

By means of BF_3 detectors with paraffin sheaths only, the distribution of the fast and thermal component— i.e., a number proportional to the total flux— was determined as shown in Figure 1, curve b. When a cadmium sheath was placed outside the paraffin to remove the thermal component, the flux distribution was the same shape as shown in curve a. The flux difference, which is small, accounts for the thermal fraction. Using bare detectors, a

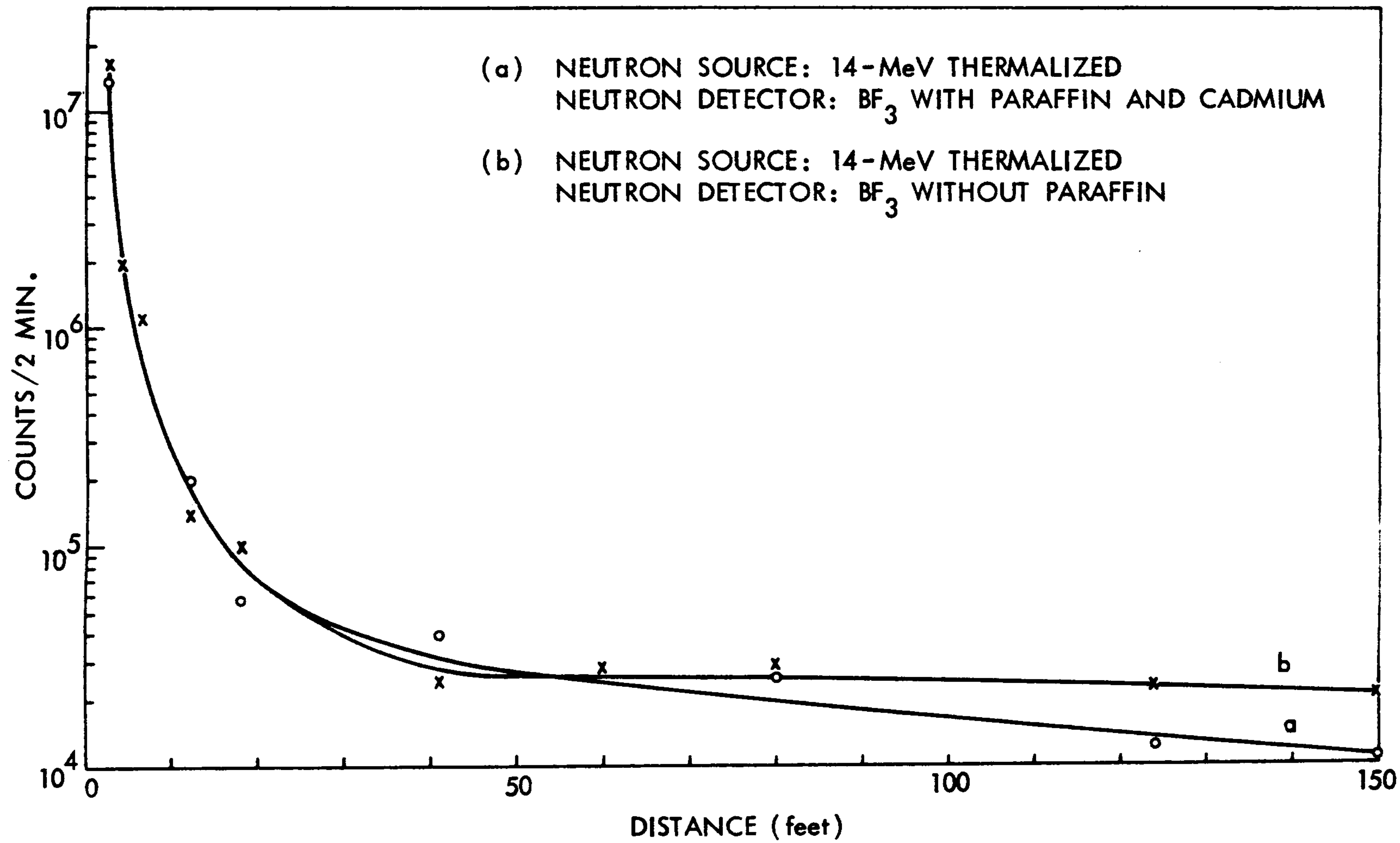

Figure 1. Gross Thermal Neutron Flux Versus Distance for Non-Thermalized 14-Mev Neutrons

similar measurement was made under the same conditions. The resultant distribution as shown by Figure 2, curve b, is a direct measurement of the thermal and epithermal component. Figure 2, curve a, shows the flux distribution measured with the holes covered with 0.013 inch of cadmium and 4 inches of paraffin. This curve represents the thermal component from the environment around the hole and the epithermal component from the air and hole, but not the thermal component that originates in the air. At distances less than 50 feet, thermalization of the fast component apparently does not occur, because the paraffin moderator is too thin to thermalize a sufficient fraction of the high-energy component. Beyond 50 feet, increased air scattering reduces the average energy and increases the efficiency of the moderator.

From the variation of the cross sections with neutron energy, Figure 3, for paraffin, cadmium, and boron, the results given in Figures 1 and 2 are apparent. At energies greater than 1 ev but less than 100 ev the cross section of paraffin and cadmium are low compared to that of boron and are relatively constant at higher energies. Hence, the BF_3 bare detectors used to collect the data in Figure 2 are efficient for energies less than 1 ev relative to paraffin and cadmium, but not for higher energies. For distances less than 50 feet, the curves for covered and uncovered holes (Figure 2) are essentially the same. The neutron flux in the region of 50-foot radius is therefore relatively rich in neutron energies above 1 ev; i.e., the ratio of the epithermal and higher energy neutrons to thermal neutron energies is very high. At distances over 50 feet, this ratio is lower; i.e., the neutron spectrum becomes softer. Figure 2, curve b, shows that part of the total neutron flux which is less than 10 ev. With the paraffin-cadmium cover in place (curve a), the detectors record only the epithermal component produced both by air scattering and by the paraffin layer. At 150 feet the thermal component from the air (difference between curves a and b) is about 50 percent of the total flux. Thus, 50 percent

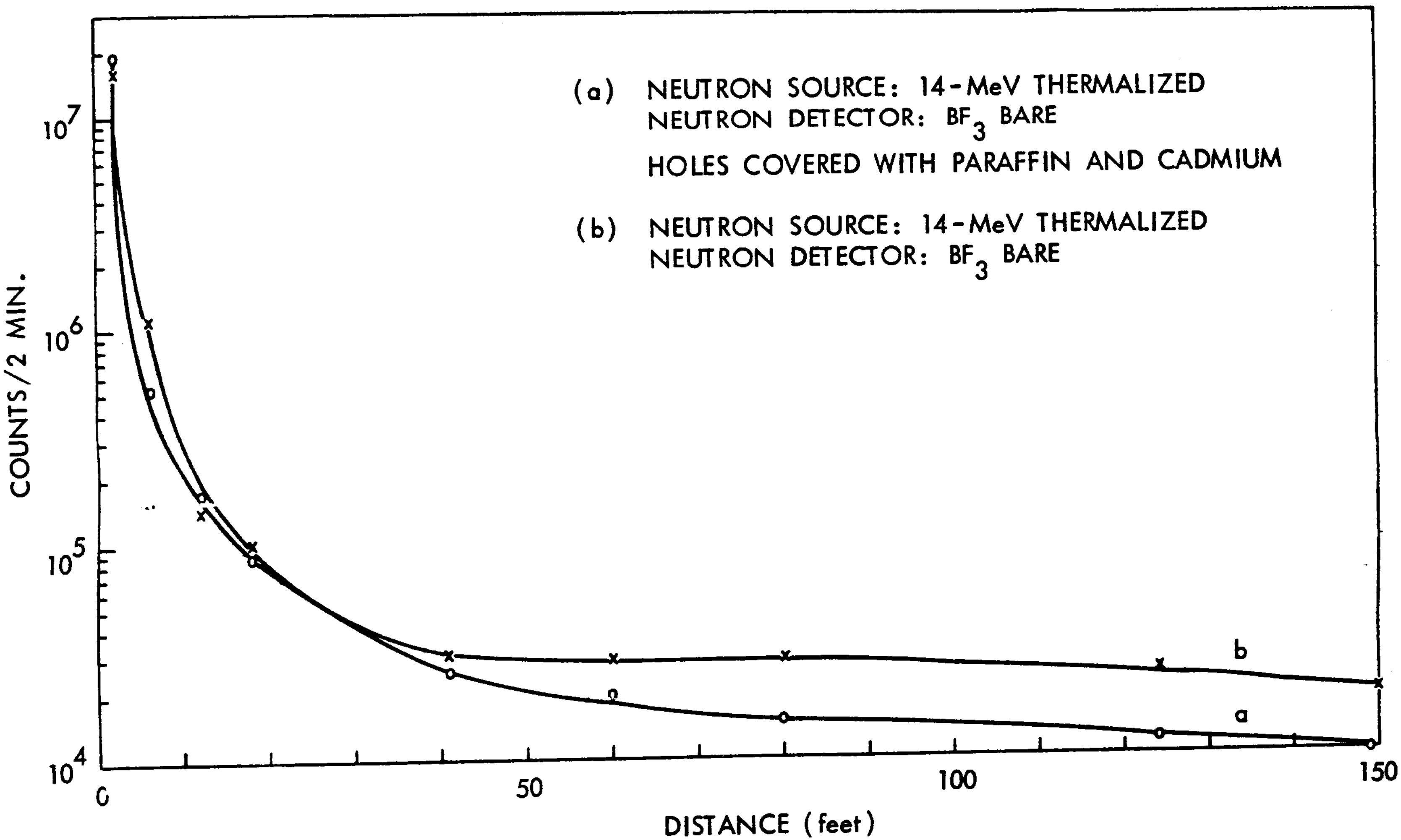

Figure 2. Gross Thermal Neutron Flux Versus Distance for Thermalized 14-Mev Neutrons

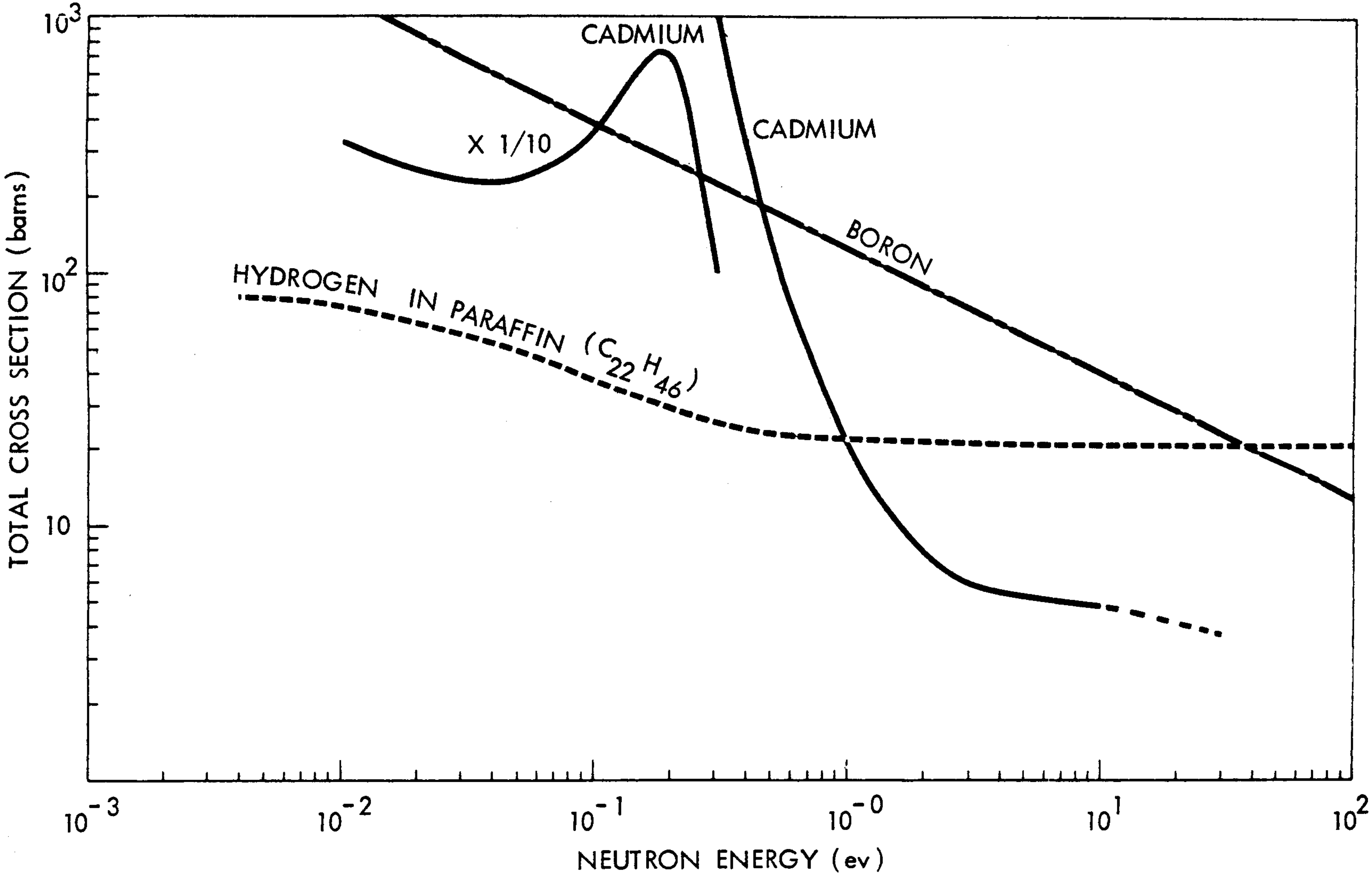

Figure 3. Neutron Cross Section Versus Energy for Cadmium, Boron, and Hydrogen in Paraffin. Data Taken from Reference 12

of the thermal flux is emitted from the soil around the hole; but this does not necessarily mean that these neutrons traveled through 150 feet of soil before thermalization.

Unmoderated Neutrons

With an unmoderated source of 14-Mev neutrons, and the BF_3 detectors clad in paraffin only, the relative total flux was determined as shown in Figure 4, curve a. A cadmium sheath was then placed outside the paraffin to remove the thermal component (curve b). A peak occurs in the distribution in both cases and is apparently due to the fast component. To confirm the source of the peak, the thermal and epithermal fractions of the total flux were measured with bare-BF_3 detectors, as shown in Figure 5, curve a. The holes were then covered with paraffin-cadmium covers to remove the thermal component from the air. No peak was observed in either case; the results generally agree with those shown for the moderated neutron flux in Figure 2.

The peak in the neutron distribution at 55 feet shown in Figure 4 was first thought to be due to some natural scatterer below ground causing an anomalous reflection. To check this explanation, the accelerator was moved approximately to a point 21.5 feet from the original source location and in the direction of the last hole. Figure 6 shows the flux distribution for the remaining five detectors clad in paraffin. The peak is less intense and is about 100 feet from the neutron source instead of 55 feet, as in Figure 4, curve a. The minimum in both figures is about half the distance between the source and the point of maximum peak intensity. The pattern of these results suggests that the peak in the distribution curve is due simply to the efficiency of the detectors and the air-soil interface scattering. Close to the neutron source the neutron albedo is relatively large and falls off roughly as $1/r_2$. As the total flux decreases, the spectral distribution shifts toward lower energies, and the degree of softening is a function of the total scattering, i.e., directly

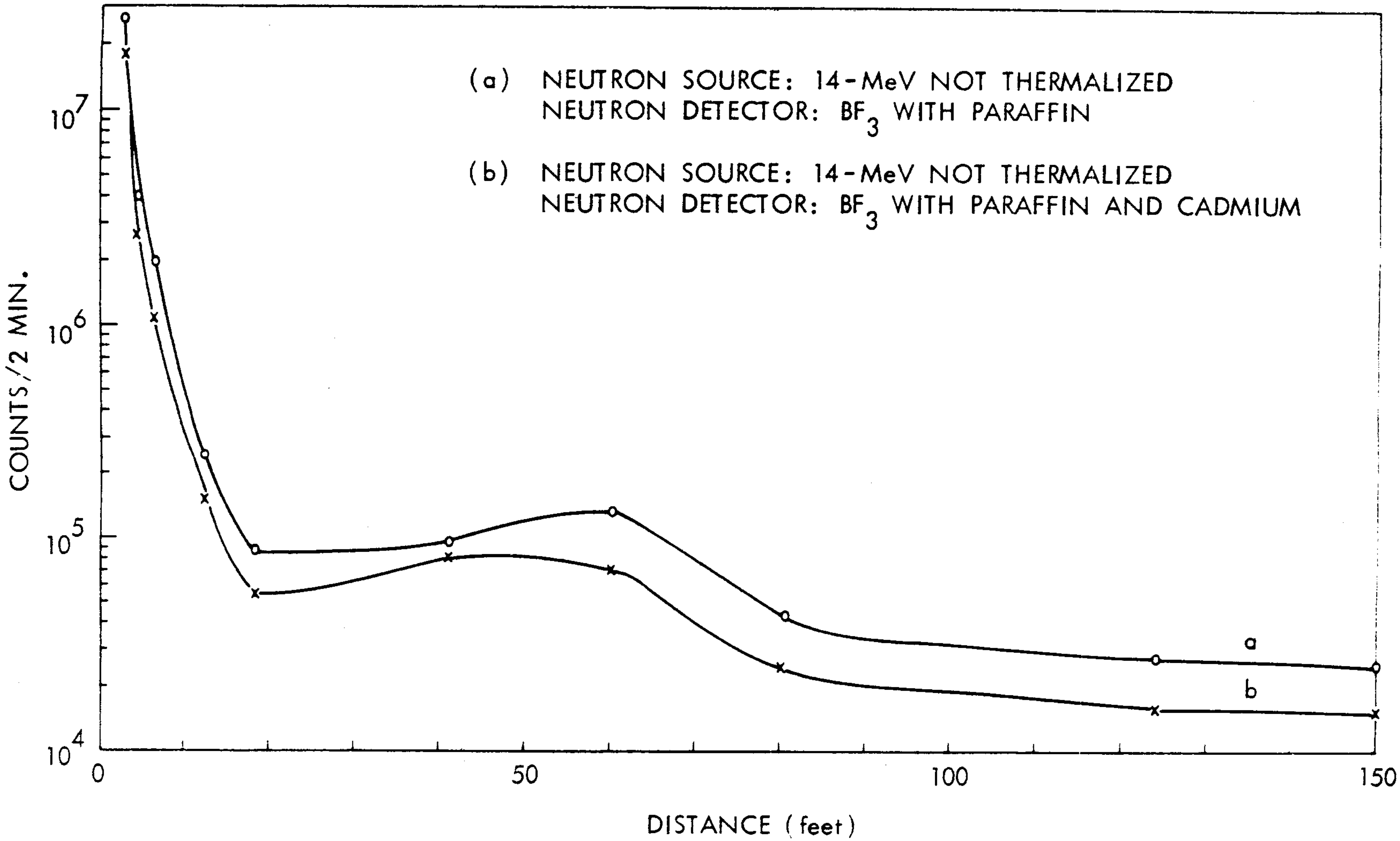

Figure 4. Gross Non-Thermal Neutron Flux Versus Distance for Non-Thermalized 14-Mev Neutrons

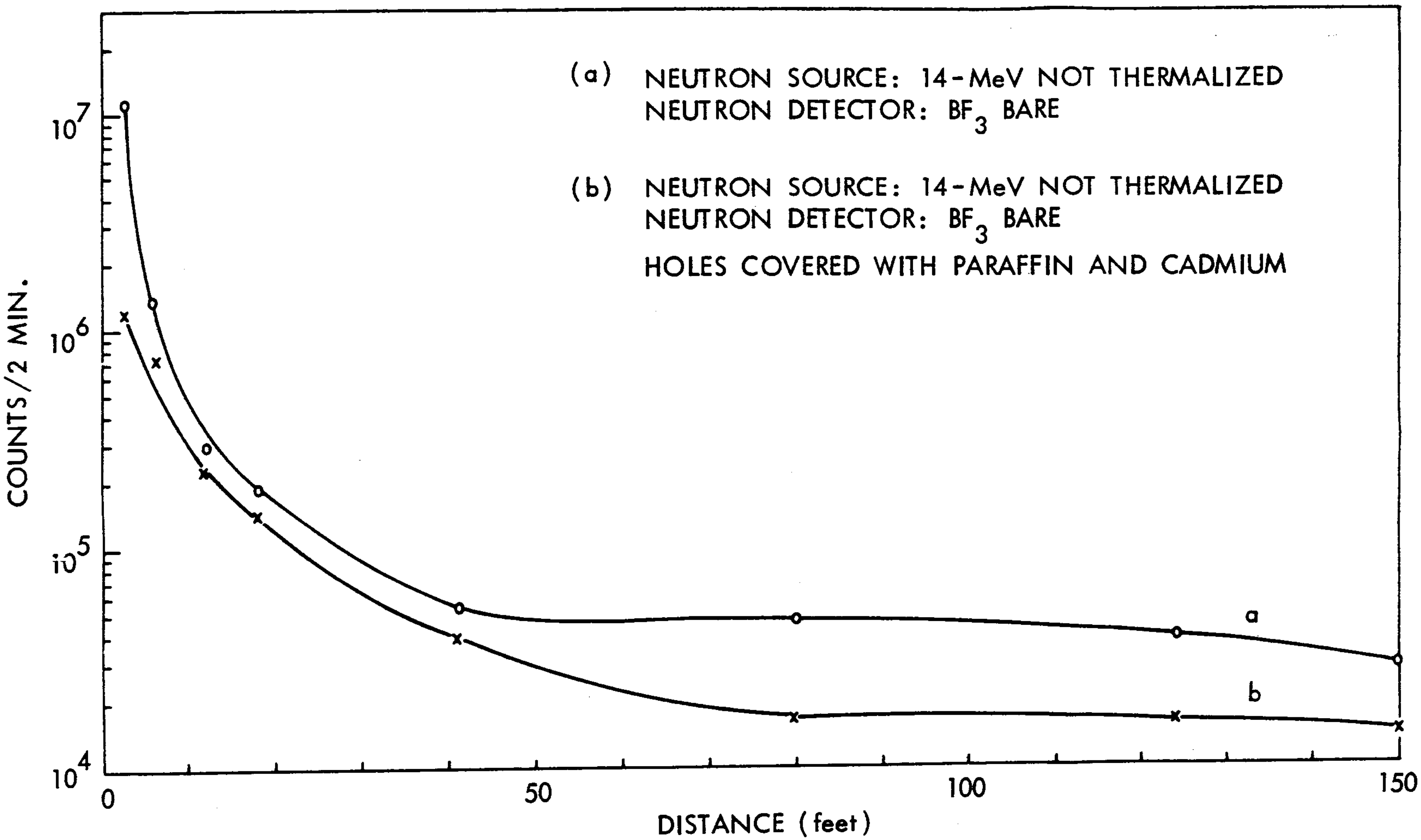

Figure 5. Gross Non-Thermal Neutron Flux Versus Distance for Thermalized 14-Mev Neutrons

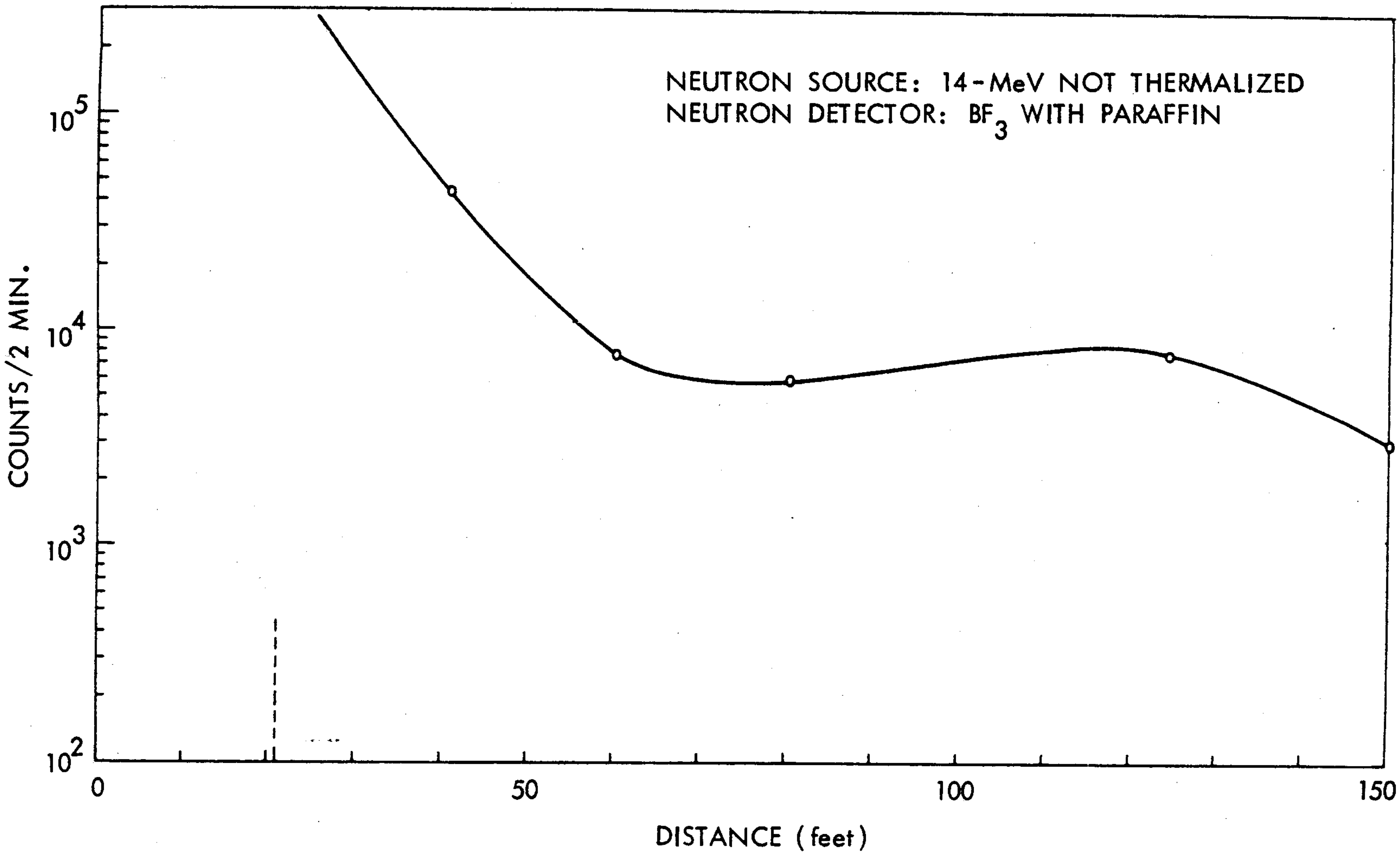

Figure 6. Gross Non-Thermal Neutron-Flux Versus Distance for Non-Thermalized; Source at 21 Feet

related to the moisture content of the air and the soil. The BF_3 detector becomes more efficient as the average energy of the neutron spectrum decreases. At some critical distance from the neutron source, the $1/r_2$ decrease in flux equals the increase that is due to the enhanced efficiency of the BF_3 detectors. The distance corresponds to the minimum in the neutron distribution curve at about 27 feet (Figure 4). At greater distances the continual decrease in the average energy of the spectrum further enhances the efficiency of the detectors, causing an increase in the flux measurements to a maximum value at 55 feet. Finally the $1/r_2$ decrease in flux overtakes the growing efficiency of the detectors, and the flux again decreases.

The above explanation of the data can be checked by putting a layer of cadmium outside the paraffin sheath to remove the thermal neutron component. The ratio of the thermal component to the fast component increases with distance from the source; hence this cadmium should preferentially decrease the flux in the peak at greater distances from the neutron source; Figure 4 shows this effect.

As the moisture content of the soil is reduced, the albedo due to scattering is reduced, and the spectrum softens at a slower rate. Thus, the minimum in the flux distribution curve must necessarily take place at a point further from the neutron source. The data in Figure 4 were observed when the soil was saturated with water, whereas data in Figure 5 were taken under considerably drier conditions. The lower intensity and greater distance of the peak compared to that in Figure 4 simply reflects the moisture content of the soil.

To check the effect of neutron source height above the ground, the neutron generator was raised to 16.5 inches and then to 32.5 inches. Neutron distribution curves obtained at each height were essentially the same as when the source was at ground level except that the counting rates went up slightly with height. With the source at ground level, and the detector at 60 feet from the source, the effect of detector height was observed by raising the BF_3 detectors to several points above the interface. Table 2 shows the counting rates. A significant increase in flux was noted at the interface, but not above. Essentially 90 percent of the counts observed just below the interface are due to neutrons coming into the hole from the air.

SUMMARY AND CONCLUSIONS

With a 14-Mev positive-ion-accelerator source of neutrons, the distribution of neutrons at the air-ground interface was measured at distances up to 150 feet. When the source was moderated, the thermal and fast components had normal $1/r_2$ distribution. However, when the unmoderated source was used, the fast component showed a peak superimposed on a $1/r_2$ distribution, whereas the thermal component showed a normal $1/r_2$ distribution. The maximum in the fast-component distribution is explained as the result of a softening of the neutron spectrum with the distance from the source, accompanied by an increasing efficiency of the detector together with the normal $1/r_2$ decrease in flux.

These measurements are important when in situ measurements are made by a neutron gamma method to directly determine one or more geochemically significant components in the ground. Semi-quantitative results are required, in order to give reasonable estimates that can be used to solve problems of natural resource development. A knowledge of the neutron spectral distribution has been found necessary, in order to accurately interpret the experimental data. The data presented in this paper are an attempt to obtain basic information for a given set of field conditions. This information enables one to determine in a semi-quantitative way the neutron energy distribution within the semi-infinite sample. The observed gamma spectra will depend on this neutron energy distribution. A knowledge of this distribution will facilitate the resolution and identification of the discrete gamma-energy peaks.

Table 2

Neutron Counts in 2-Minute Period at Several Heights Above the Ground and 60 Feet from Neutron Source

Height	Normalized Counts
8 inches below ground level	8,877
	959*
36	40,405
72	40,000
121	45,969

*Hole covered with 4 inches paraffin and 0.013 inches of cadmium.

REFERENCES

1. Caldwell, R. C., Mills, W. R., Jr., Allen, L. S., Bell, P. R., and Heath, R. L.: Combination Neutron Experiment for Remote Analysis, Science, vol. 152, no. 3721, 1966, pp. 457-465.

2. Trombka, J. I., and Metzger, A. E.: Neutron Methods for Lunar and Planetary Surface Compositional Studies, in Analysis Instruments 1963, Plenum Press, 1963.

3. Senftle, F. E., and Hoyte, A. F.: Mineral Exploration and Soil Analysis Using in situ Neutron Activation, Nuc. Instr. and Methods, vol. 42, 1966, pp. 93-103.

4. Hoyte, A. F., Martinez, P., and Senftle, F. E.: Neutron Activation Method for Silver Exploration, AIME Trans. 1967, vol. 238, 1967, pp. 94-102.

5. Senftle, F. E., Sarigianis, P., and Philbin, P.: Neutron Activation Techniques for Precious Metal Exploration, Proc. Canadian Conf. Min. Groundwater Geophys., Geol. Survey Can., 1968, in press.

6. Reed, J. H., Mandler, J. W., and Terrel, C. W.: Compositional Analysis of Lunar and Planetary Surfaces with Pulsed 14-MeV Neutron-Produced Thermal-Neutron Capture Gamma Rays, ANS Trans., vol. 10, no. 1, 1967, p. 27.

7. Mills, W. R., Jr., Givens, W. W., and Caldwell, R. L.: Neutron Die-Away Experiment for Lunar and Planetary Surface Analysis, ANS Trans. vol. 10, no. 1, 1967, p. 33.

8. Fite, L. I., Steele, D. L., and Wainardi, R. E.: An Investigation of Remote Lunar Analysis by Nuclear Activation Analysis, NASA Goddard Space Flight Center, Technical Information Division, 19999, 1963.

9. Allen, F., Futterer, A., and Wright, W.: Ballistic Research Laboratory Reports nos. 1189, 1190, and 1199 (Aberdeen Proving Ground, Maryland), 1963.

10. Tomnovic, F., and Ferguson, J.: Neutron-Field and Induced-Activity Measurements-Operation Bren, AEC Report CEX-62.50, 1965.

11. Haywood, F., Auxier, J., and Loy, E.: An Experimental Investigation of the Spatial Distribution of Dose in an Air-Over-Ground Geometry, AEC Report CEX-62.14, 1964.

12. Division of Radiological Health: Radiological Health Handbook, U. S. Dept. of Health, Education and Welfare, Washington 25, D. C., Sept. 1960, pp. 174 and 175.